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(71) Applicant: **ASM LITHOGRAPHY B.V.**
5503 LA Veldhoven (NL)

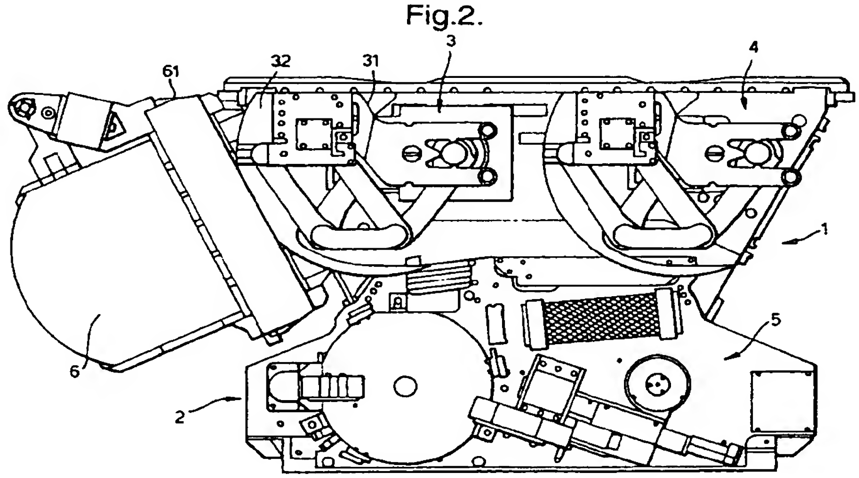
(72) Inventors:
- **Segers, Hubert Marie**
  5212 's Hertogenbosch (NL)
- **Boon, Rudolf Maria**
  5653 RM Eindhoven (NL)
- **Bijnagte, Anton Adriaan**
  4196 AB Tricht (NL)
- **Jacobs, Fransiscus Mathijs**
  5721 DE Asten (NL)

(74) Representative:
Leeming, John Gerard
J.A. Kemp & Co.,
14 South Square,
Gray's Inn
London WC1R 5LX (GB)

(54) **Substrate handler for use in lithographic projection apparatus**

(57) A pre-aligner receives wafers from a wafer carrier of process track and performs preparatory steps such as centering of the wafer. The prepared wafer is transferred to the wafer table using a robot arm that is isolated from the pre-aligner and the wafer table. The robot arm couples to the pre-aligner to pick-up the wafer, decouples, couples to the wafer table and deposits the wafer. Positional accuracy of the wafer is thereby maintained during the transfer.

Fig.2.



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Description

[0001] The present invention relates to substrate, e.g. wafer, handling apparatus. More particularly, the invention relates to a substrate handler for use in a lithographic projection apparatus comprising:

a radiation system for supplying a projection beam of radiation;
a mask table provided with a mask holder for holding a mask;
a substrate table provided with a substrate holder for holding a substrate;
a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate;
a pre-aligner for carrying out an initial alignment of a substrate; and
a substrate handler for transferring a substrate from said pre-aligner to said substrate table.

[0002] For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, catadioptric systems, and charged particle optics, for example. The radiation system may also include elements operating according to any of these principles for directing, shaping or controlling the projection beam, and such elements may also be referred to below, collectively or singularly, as a "lens".

[0003] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the mask (reticle) may contain a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto an exposure area (die) on a substrate (silicon wafer) which has been coated with a layer of photosensitive material (resist). In general, a single wafer will contain a whole network of adjacent dies, which are successively irradiated via the reticle, one at a time. In one type of lithographic projection apparatus, each die is irradiated by exposing the entire reticle pattern onto the die in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus - which is commonly referred to as a step-and-scan apparatus - each die is irradiated by progressively scanning the reticle pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table (wafer table) parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the wafer table is scanned will be a factor M times that at which the mask table (reticle table) is scanned. More information with regard to lithographic devices as here described can be gleaned from International Patent Application WO97/33205, for example.

[0004] Until very recently, lithographic apparatus contained a single mask table and a single substrate table. However, machines are now becoming available in which there are at least two independently moveable substrate tables; see, for example, the multi-stage apparatus described in International Patent Applications WO98/28665 and WO98/40791. The basic operating principle behind such multi-stage apparatus is that, while a first substrate table is at a exposure position underneath the projection system for exposure of a first substrate located on that table, a second substrate table can run to a loading position, discharge a previously exposed substrate, pick up a new substrate, perform same initial measurements on the new substrate and then stand ready to transfer the new substrate to the exposure position underneath the projection system as soon as exposure of the first substrate is completed; the cycle then repeats. In this manner it is possible to increase substantially the machine throughput, which in turn improves the cost of ownership of the machine. It should be understood that the same principle could be used with just one substrate table which is moved between exposure and measurement positions.

[0005] In a known lithography apparatus, substrates for exposure - such as wafers - can be first loaded from a wafer carrier or process track into a pre-align module, so as to prepare the substrates for exposure. One of the most important aspects of such preparation is a prealignment step. In this step, the wafer is placed on a pre-aligner turntable and its edge inspected by rotating it past an edge sensor, which may comprise an optical or capacitive sensor, for example. This enables automatic location of the notch or flat edge of the wafer, and also allows the eccentricity of the wafer on the turntable to be measured. In this way:

- the notch or flat edge can be automatically oriented as desired, before the wafer is transferred to the substrate table;
- It can be determined if the eccentricity of the wafer exceeds a threshold value which, when translated to the substrate table, would cause the wafer to fall outside the capture range of an alignment module employed at the substrate table. If such is the case, then the wafer can first be shifted on the turntable by a pre-calculated amount, so as to bring it within the threshold value.

Once these steps have been performed, a substrate handler can remove the wafer from the turntable and place it on the wafer table with a precision which will allow wafer capture by the alignment module.

[0006] However, the present inventors have determined that the various activities of the pre-aligner are a source of undesirable vibrations which can induce overlay errors if pre-alignment steps are carried out whilst another wafer is being exposed. It is undesirable to not

perform pre-alignment concurrently with exposures as this reduces throughput. Also, if the pre-aligner is mechanically isolated from the wafer table to prevent transmission of vibration, their relative position will no longer be certain to a sufficient accuracy to allow the substrate handler to transfer the wafer to the wafer table with the required precision.

[0007] An object of the present invention is to provide a substrate handler capable of transferring substrates from a pre-aligner to a substrate table in a lithographic projection apparatus whilst avoiding the transmission of vibrations to the substrate table when pre-alignment steps are carried out on one substrate concurrently with exposure of another substrate.

[0008] According to the present invention there is provided a lithographic projection apparatus comprising:

> a radiation system for supplying a projection beam of radiation;
> a mask table provided with a mask holder for holding a mask;
> a substrate table provided with a substrate holder for holding a substrate;
> a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate;
> a pre-aligner for carrying out an initial alignment of a substrate; and
> a substrate handler for transferring a substrate from said pre-aligner to said substrate table;
> characterized in that:
> said pre-aligner is mechanically isolated from said substrate table; and by
> coupling means for selectively coupling said substrate handler to said substrate table at a known relative position.

[0009] Because the pre-aligner of the present invention is mechanically isolated from the substrate table, which carries the substrate during exposure processes, vibrations caused by the pre-alignment steps are not transmitted to the substrate during exposure. To provide positional accuracy in the transfer of substrates, the substrate handler couples to the substrate table to define its position relative thereto and only then deposits the substrate in the substrate holder. The substrate handler can have a fixed position relative to the pre-aligner or may be mechanically isolated from it as well and couple to it to pick up the substrate. Coupling to the pre-aligner ensures that, even if the substrate handler is isolated from the pre-aligner, it is at a known, e.g. predetermined, position relative to the pre-aligner when the substrate is picked up so that it will be held in the substrate handler at a known position. Similarly, when the substrate handler is coupled to the substrate table, its relative position is known and the positional accuracy of the substrate when in the pre-aligner is preserved in the transfer. If the substrate handler couples to both the substrate table and the pre-aligner, its relative position is known relative to the pre-aligner when the substrate is picked up from that pre-aligner and its relative position is known relative to the substrate table when the substrate is deposits, such that the accuracy of the pre-aligning is maintained during the transfer.

[0010] In preferred embodiments, when the substrate handler approaches the pre-aligner or substrate table their relative positions are known only coarsely. Once the substrate handler has made an initial contact with the pre-aligner or substrate table an automatic coupling mechanism brings the two together in a predetermined physical relationship. This can be achieved using an end-effector member on the substrate handler, which is loosely coupled to the substrate handler. The end-effector member carries half of a coupling which mates with corresponding halves on the pre-aligner and substrate table. The two halves of the coupling are mechanically biased to take up the correct position on coupling, without the necessity for the substrate handler as a whole to be as accurately aligned to the substrate table.

[0011] According to a further aspect of the present invention there is provided a method of manufacturing a device using a lithographic projection apparatus comprising:

> a radiation system for supplying a projection beam of radiation;
> a mask table provided with a mask holder for holding a mask;
> a substrate table provided with a substrate holder for holding a substrate;
> a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; and
> a pre-aligner for carrying out an initial alignment of a substrate; the method comprising the steps of:
> providing a mask bearing a pattern to said mask table;
> providing a substrate having a radiation-sensitive layer to said pre-aligner and preparing it for exposure;
> transferring said substrate from said pre-aligner to said substrate table using a substrate handler; and
> imaging said irradiated portions of the mask onto said target portions of the substrate;
> characterized in that:
> said step of transferring said substrate from said pre-aligner comprises the sub-steps of:
>
> > picking up said substrate from said pre-aligner;
> > coupling said substrate handler to said substrate table;
> > placing said substrate in said substrate holder of said substrate table.

[0012] In a manufacturing process using a litho-

graphic projection apparatus according to the invention a pattern in a mask is imaged onto a substrate which is at least partially covered by a layer of energy-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices (dies) will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4.

[0013] Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "exposure area", respectively.

[0014] In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation or particle flux, including, but not limited to, ultraviolet radiation (e.g. at a wavelength of 365nm, 248nm, 193nm, 157nm or 126nm), extreme ultraviolet radiation (EUV), X-rays, electrons and ions. Also herein, the invention is described using a reference system of orthogonal X, Y and Z directions and rotation about an axis parallel to the *I* direction is denoted R*i*. Further, unless the context otherwise requires, the term "vertical" (Z) used herein is intended to refer to the direction normal to the substrate or mask surface, rather than implying any particular orientation of the apparatus.

[0015] The present invention will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

Figure 1 depicts a lithographic projection apparatus according to a first embodiment of the invention;

Figure 2 depicts a pre-aligner and substrate handler of the first embodiment;

Figure 3 depicts the pre-aligner and substrate handler of the first embodiment with a wafer placed on the pre-aligner;

Figure 4 depicts the pre-aligner and substrate handler of the first embodiment with a wafer on the substrate handler, which is extended;

Figures 5A to 5C depict a pre-aligner and substrate handler of a second embodiment of the invention;

Figures 6A and 6B depict the substrate handler and wafer table of the second embodiment of the invention;

Figure 7 depicts a coupling mechanism of a third embodiment of the invention;

Figure 8 depicts the coupling mechanism of the third embodiment when the substrate handler is at a slight angle to the pre-aligner; and

Figure 9 depicts the coupling mechanism of the third embodiment with the end-effector correctly aligned with the pre-aligner.

[0016] In the drawings, like references indicate like parts.

<u>Embodiment 1</u>

[0017] Figure 1 schematically depicts a lithographic projection apparatus according to the invention. The apparatus comprises:

- a radiation system LA, Ex, IN, CO for supplying a projection beam PB of radiation (e.g. UV or EUV radiation, electrons or ions);
- a mask table MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a substrate table (wafer table) WT provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL (e.g. a refractive or catadioptric system, a mirror group or an array of field deflectors) for imaging an irradiated portion of the mask MA onto an exposure area C (die) of a substrate W held in the substrate table WT.

[0018] As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example.

[0019] The radiation system comprises a source LA (e.g. a Hg lamp, excimer laser, an undulator provided around the path of an electron beam in a storage ring or synchrotron, a laser plasma source or an electron or ion

beam source) which produces a beam of radiation and an illumination system. The beam is passed along various optical components comprised in the illumination system - e.g. beam shaping optics Ex, an integrator IN and a condenser CO - so that the resultant beam PB has a desired shape and intensity distribution in its cross-section.

[0020] The beam PB subsequently intercepts the mask MA which is held in the mask holder on the mask table MT. Having passed through the mask MA, the beam PB passes trough the lens PL, which focuses the beam PB onto an exposure area C of the substrate W. With the aid of an interferometric displacement and measuring means IF, the substrate table WT can be moved accurately by the second positioning means, e.g. so as to position different exposure areas C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the pat of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library. In general, movement of the mask table MT and substrate table WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. In the case of a waferstepper (as opposed to a step-and-scan apparatus) the mask table MT may be connected only to a short-stroke positioning device or may be just fixed.

[0021] The depicted apparatus can be used in two different modes:

1. In step-and-repeat (step) mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (i.e. a single "flash") onto an exposure area C. The substrate table WT is then shifted in the X and/or Y directions so that a different exposure area C can be irradiated by the beam PB;
2. In step-and-scan (scan) mode, essentially the same scenario applies, except that a given exposure area C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the Y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, M = 1/4 or 1/5). In this manner, a relatively large exposure area C can be exposed, without having to compromise on resolution.

[0022] Figure 2 shows a pre-align unit 1 comprising a pre-aligner 2 and wafer handling components. After a wafer has been transferred from a wafer carrier or process track to the pre-aligner 2, the pre-alignment process is started. Pre-alignment may include wafer edge detection, e.g. using an optical sensor, wafer centering and temperature conditioning. The pre-alignment process and pre-aligner are described further in a concurrently filed application entitled "Lithographic Projection Apparatus" (Applicant's reference P-0135.010), for example.

[0023] Once pre-alignment is complete, the wafer is transferred to a wafer table WT by load robot 3 (the "substrate handler"). The load robot 3 is equipped with an independent and separate trajectory safeguard system in order to prevent wafer breakage. During operation of the load robot 3, measured absolute position and derived velocity of the load robot 3 are compared with permitted position and velocity. Remedial action can be taken in the event of divergence. The position of the wafer on the pre-aligner 2 is known with high accuracy and it must be placed on the wafer table WT with the required accuracy, i.e. within the capture range of the alignment system employed at the wafer table WT. To this end, the load robot 3 is provided with a docking unit (the "coupling means") 31 which couples to the pre-aligner 2 when taking up the wafer W and to the wafer table WT when pulling it down. The docking unit 31 may be of the ball/groove kinematic coupling type with the ball provided on the docking unit 31 and grooves on the pre-aligner 2 and wafer table WT. Preferably, the docking unit 31 couples to the pre-aligner 2 and wafer table WT at two spaced apart positions. For safety reasons the rotating part of the load robot 3 is provided with a light shield 32 to prevent any stray light from the exposure position escaping to the pre-align unit 1 or process track.

[0024] After full exposure, an unload robot 4 transfers the wafer W from the wafer table WT to a discharge station 5. The unload robot 4 may be constructed similarly to the load robot 3, but does not have such high accuracy requirements. The wafer W is taken from the discharge station 5, also referred to as the pedestal, to the wafer carrier 6 or process track. The unload robot 4 can also be used to load wafers from the pre-aligner 2 to the wafer table WT. Conversely, the load robot 3 can also be used to transfer wafers from the wafer table WT to the discharge station 5 or the wafer carrier 6.

[0025] Pre-align unit 1 may further be provided with a cater handler 61 which enables the use of different types of wafer carriers, such as 200mm and 300 mm cassette carriers. The carrier handler 61 can be configured on either the left or right side of the lithographic projection apparatus and arranges for accepting and (if applicable) locking wafer carrier 6, inspecting and indexing wafer cater 6 and (if applicable) opening cater 6 and removing wafers. The cater handler 61 can be used to store rejected wafers or wafers that need further processing. in the wafer cater 6.

[0026] In Figure 3, the pre-align unit 1 is shown in a first loaded position. In this position. the pre-aligner 2 contains a wafer 71, which has been pre-aligned and conditioned, whilst the load robot 3 is positioned to transfer the wafer 71, after half rotation of the load robot 3, to the wafer table WT. The unload robot 4 carries a

wafer 72, which has been removed from the wafer table WT after exposure, and which, after half rotation of the unload robot 4, will be transferred to the discharge station 5.

[0027] In Figure 4, the same pre-align unit 1 is shown but with arm 33 of the load robot 3 extended for transfer of wafer 71 to the wafer table WT. The exposed wafer 72 is still on the unload robot 4.

Embodiment 2

[0028] Figures 5A to 5C, 6A and 6B show schematically a load robot (substrate handler) 130 of a second embodiment of the invention. Functionally, and save as described below, the second embodiment is the same as the first embodiment.

[0029] Load robot 130 comprises a two-part arm 131 which is rotatable mounted to base 132 so that the arm can extend from the position shown in Figures 5A and B to reach a pre-aligner 2, as shown in Figure 5C, and a wafer table. A pick-up hand 133 is provided on the end of arm 131 and has two fingers 134 which are inserted underneath wafer W, as shown in Figure 5C, to pick-up the wafer W. Pick-up hand 133 also carries one coupling half 135a of which mates with a corresponding coupling half 135b (the "coupling means") provided on the pre-aligner 2. The coupling 135a, 135b is used to ensure that the pick-up hand 133 is accurately positioned relative to the pre-aligner 2 when the wafer W is picked up. The connection between pick-up hand 133 and arm 131 allows a certain amount of movement between them so that the pick-up hand can be moved into correct alignment by the coupling 135a, 135b even if the arm 131 is not perfectly aligned. Hence, the wafer is accurately positioned on the pick-up hand 133 and can be placed on the wafer table WT with corresponding accuracy.

[0030] Figures 6A and B show the wafer table WT which is moveable. As such it can be brought to a predetermined position relative to a fixed member 136 which carries another half coupling 135c to mate with the coupling half 135a provided on the pick-up hand 133.

Embodiment 3

[0031] A coupling mechanism used in a third embodiment of the invention is shown schematically in Figures 7, 8 and 9. Otherwise, the third embodiment is similar in form and function to the first and second embodiment.

[0032] As shown in Figure 7, the coupling means of the third embodiment comprises a frame 235a fixed to a robot arm 231 (substrate handler) and a docking plate 235b fixed to the wafer pre-aligner 2. A similar docking plate is attached to the wafer table WT. An end-effector member 301 is loosely attached to the frame 235a and carries two sets of roller bearings 302, 303 and 306, 307. The first set of roller bearings 302, 303 are arranged so that when the robot arm 231 is brought into dock with the pre-aligner 2, first roller bearing 302 engages a groove 304 in the docking plate 235b whilst second roller bearing 303 bears on bearing surface 305 on the docking plate 235b. The engagement of roller bearing 302 with groove 304 fixes the position of end-effector member 301 relative to docking plate 235b in the Y direction whilst the engagement of roller bearing 303 with bearing surface 305 fixes the position of end-effector member 301 in the X direction. The third and fourth roller bearings 306, 307 of the second set engage a similar groove 308 and surface 309 when the robot arm is correctly aligned so as to similarly fix the position of end-effector member 301 relative to the frame 235a. A spring 310 couples end-effector member 301 to the frame 235a and biases it towards the position where roller bearings 306 and 307 respectively engage groove 308 and bearing surface 309. A pick up hand (e.g. the pick up hand 133 of figure 5 and 6) for picking-up the wafer is rigidly attached to the end-effector member so that when the end-effector member 301 is guided to the correct position by docking plate 235b, the pick up hand is in the correct position for picking-up the wafer. Misalignment of the end-effector member 301 relative to the frame 235a is detected by quadcell detector 311 and the position or orientation of robot arm 231 can be adjusted accordingly. The quadcell 311 is used to bring the robot arm 231 into coarse alignment with the pre-aligner 2; fine alignment is effected by the end-effector member 301 and the robot arm 231 need only be brought close enough to the correct position to allow the end-effector member 301 to move to correct alignment with the docking plate 235b. The quadcell detector 311 is also used to control whether the spring 310 is compressed enough to ensure that the roller bearings 302 and 303 are pressed against the docking plate 235b with sufficient force.

[0033] Figures 8 and 9 illustrate how this arrangement is used to ensure correct alignment between the robot arm 231 and pre-aligner 2. If the robot arm 231 approaches the pre-aligner 2 at a slight angle to correct alignment, one of the first and second roller bearings, e.g. roller bearing 302, will engage docking plate 235b first. As the robot arm 231 continues to advance, the end-effector member 301 will be pushed out of alignment with frame 235a as the other of first and second roller bearings 302, 303 comes into engagement with docking plate 235b against the biasing force of spring 310. This is the position shown in Figure 9. The pick-up hand stiffly attached to the end-effector member 301 is now in the correct position to pick-up the wafer from the pre-aligner 2. It will be noted that this coupling mechanism only locates the robot arm 231 relative to the pre-aligner 2 and wafer table WT in the XY plane. Precise location in Z is not necessary.

[0034] As mentioned above, a corresponding docking plate is provided on the wafer table WT for use in

loading the wafer W onto the wafer table WT.

[0035] Whilst we have described above specific embodiments of the invention it will be appreciated that the invention may be practiced otherwise than as described, for example the invention may also be used in reticle handling. The description is not intended to limit the invention.

Claims

1. A lithographic projection apparatus comprising:

    a radiation system for supplying a projection beam of radiation;
    a mask table provided with a mask holder for holding a mask;
    a substrate table provided with a substrate holder for holding a substrate;
    a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate;

        a pre-aligner for carrying out an initial alignment of a substrate; and
        a substrate handler for transferring a substrate from said pre-aligner to said substrate table;
        characterized in that:
        said pre-aligner is mechanically isolated from said substrate table; and by
        coupling means for selectively coupling said substrate handler to said substrate table at a known relative position.

2. Apparatus according to claim 1 wherein coupling means is further arranged to selectively couple to said pre-aligner at a known relative position.

3. Apparatus according to claim 1 or 2 wherein said coupling means comprises a member loosely mounted to said substrate handler, docking means arranged selectively to couple said member to said pre-aligner and said substrate table.

4. Apparatus according to claim 3 further comprising biasing means arranged to bias said member towards a predetermined position relative to said substrate handler.

5. Apparatus according to claim 1, 2, 3 or 4 wherein said coupling means comprises a first part provided on said substrate handler and two second parts, one provided on each of said pre-aligner and said substrate table, for coupling with said first part.

6. Apparatus according to claim 5 wherein said first part comprises a roller bearing and each of said second parts comprises a docking plate having therein a groove with which said roller bearing can be closely engaged.

7. Apparatus according to claim 6 wherein engagement of said roller bearing and said groove defines the relative position of said substrate handler and said pre-aligner or substrate table in a first direction substantially parallel to the plane of said substrate when held in said pre-aligner or said substrate table.

8. Apparatus according to claim 6 or 7 wherein said first part further comprises a second roller bearing and said docking plate further defines a bearing surface against which said second bearing can bear to define the relative position of said substrate handler and said pre-aligner or substrate table in a second direction substantially parallel to the plane of said substrate when held in said pre-aligner or said substrate table and substantially perpendicular to said first direction.

9. A method of manufacturing a device using a lithographic projection apparatus comprising:

    a radiation system for supplying a projection beam of radiation;
    a mask table provided with a mask holder for holding a mask;
    a substrate table provided with a substrate holder for holding a substrate;
    a projection system for imaging an irradiated portion of the mask onto a target portion of the substrate; and
    a pre-aligner for carrying out an initial alignment of a substrate; the method comprising the steps of:
    providing a mask bearing a pattern to said mask table;
    providing a substrate having a radiation-sensitive layer to said pre-aligner and preparing it for exposure;
    transferring said substrate from said pre-aligner to said substrate table using a substrate handler; and
    imaging said irradiated portions of the mask onto said target portions of the substrate;
    characterized in that:
    said step of transferring said substrate from said pre-aligner comprises the sub-steps of:

        picking up said substrate from said pre-aligner;
        coupling said substrate handler to said substrate table;
        placing said substrate in said substrate holder of said substrate table.

10. A device manufactured according to the method of claim 9.

Fig.1.

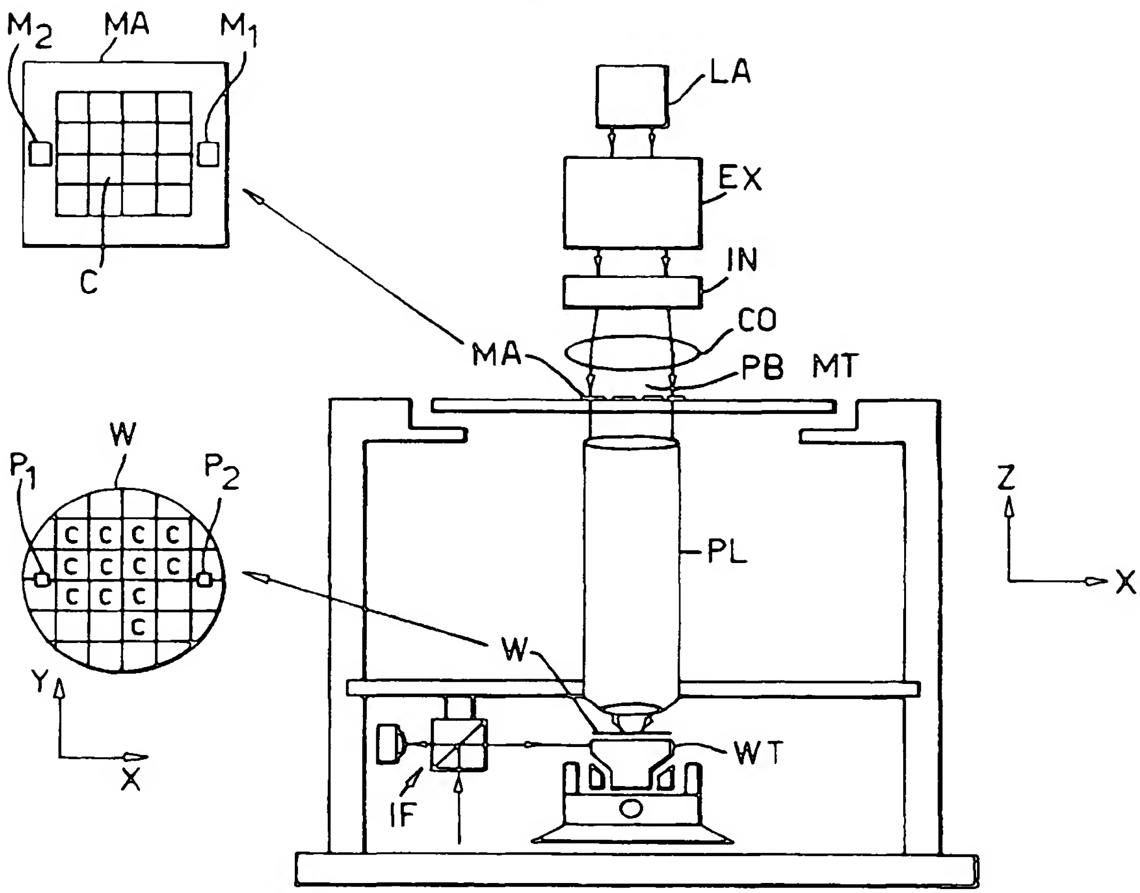
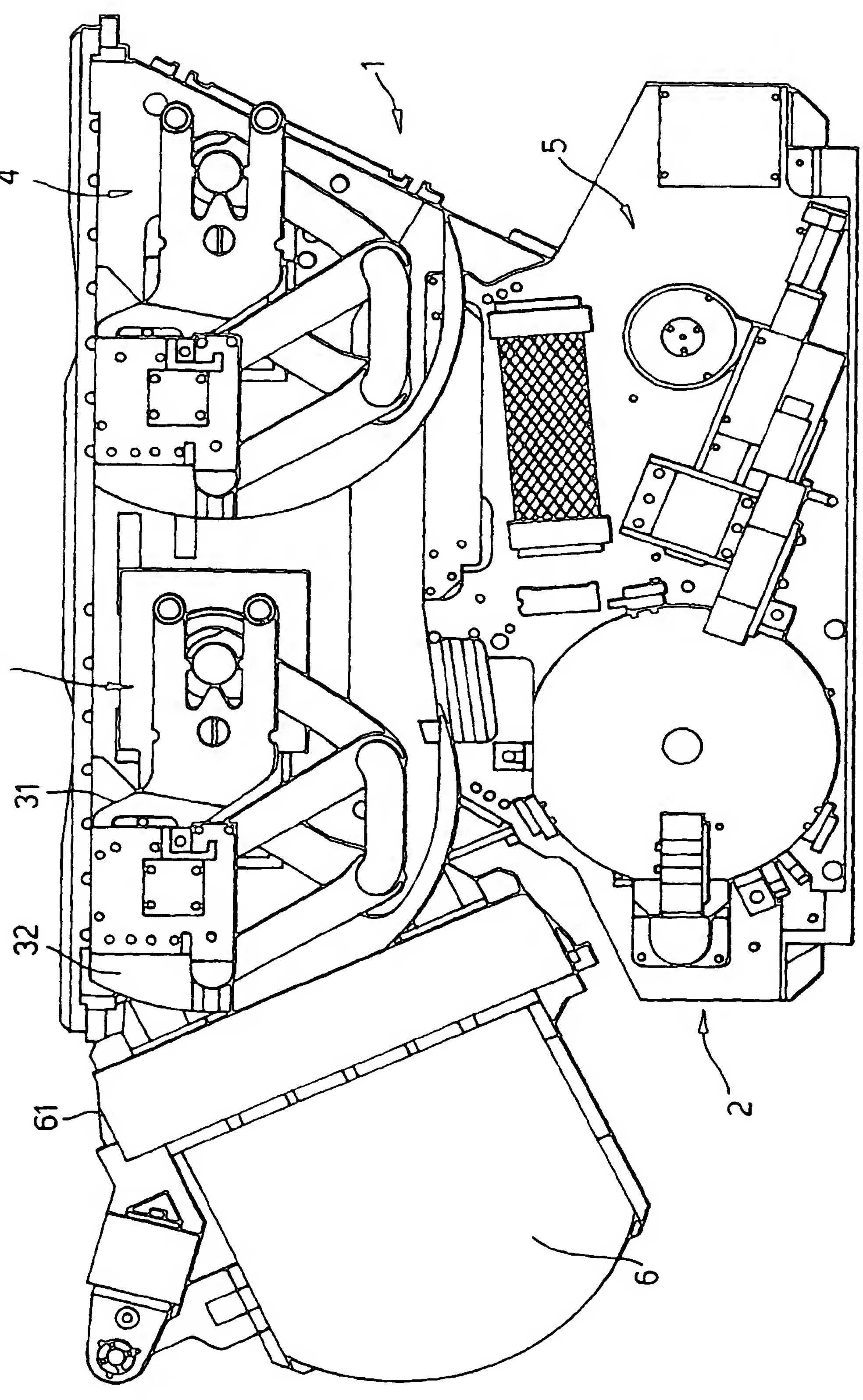


Fig.2.



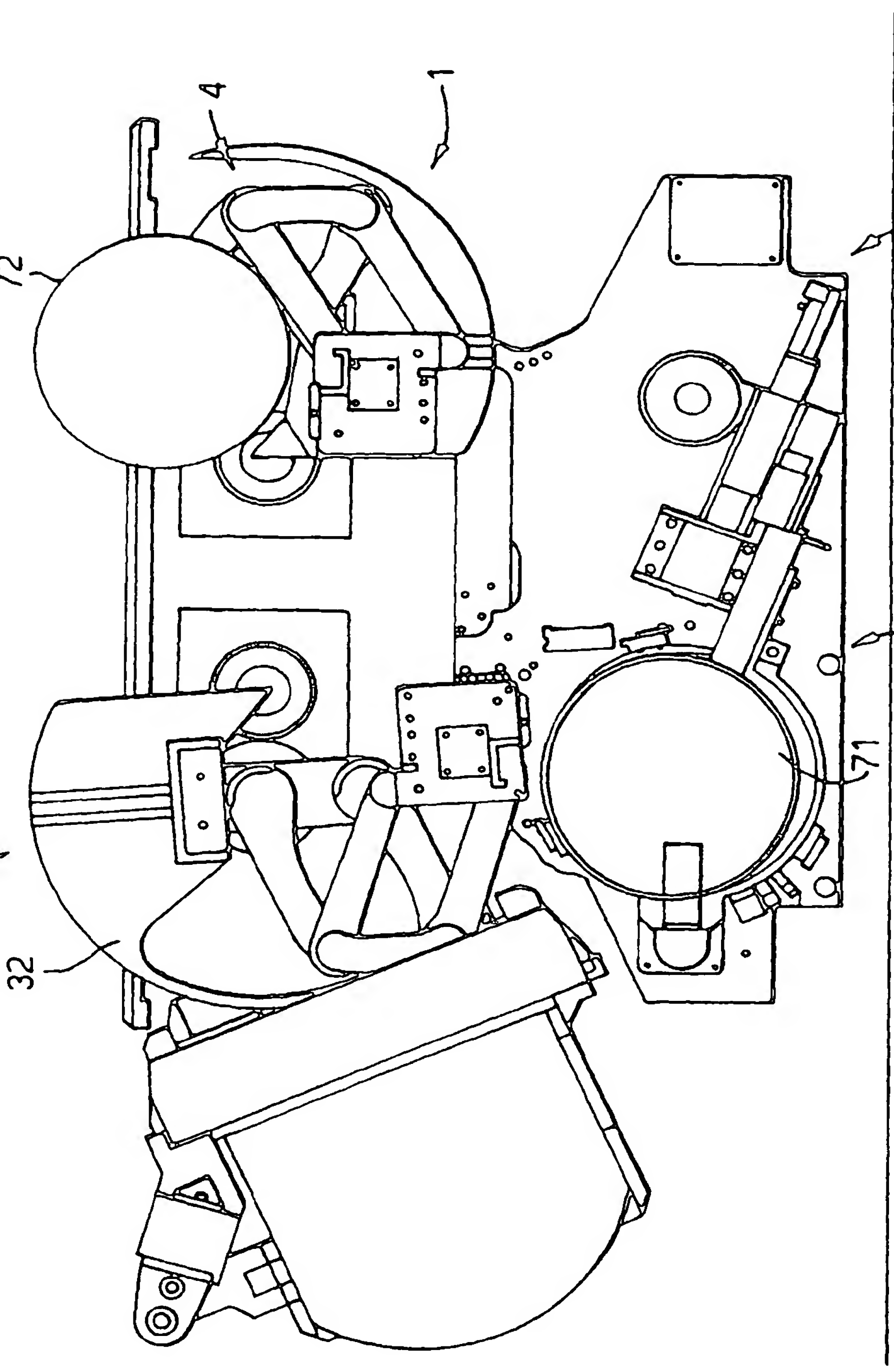


Fig.3.

Fig.4.

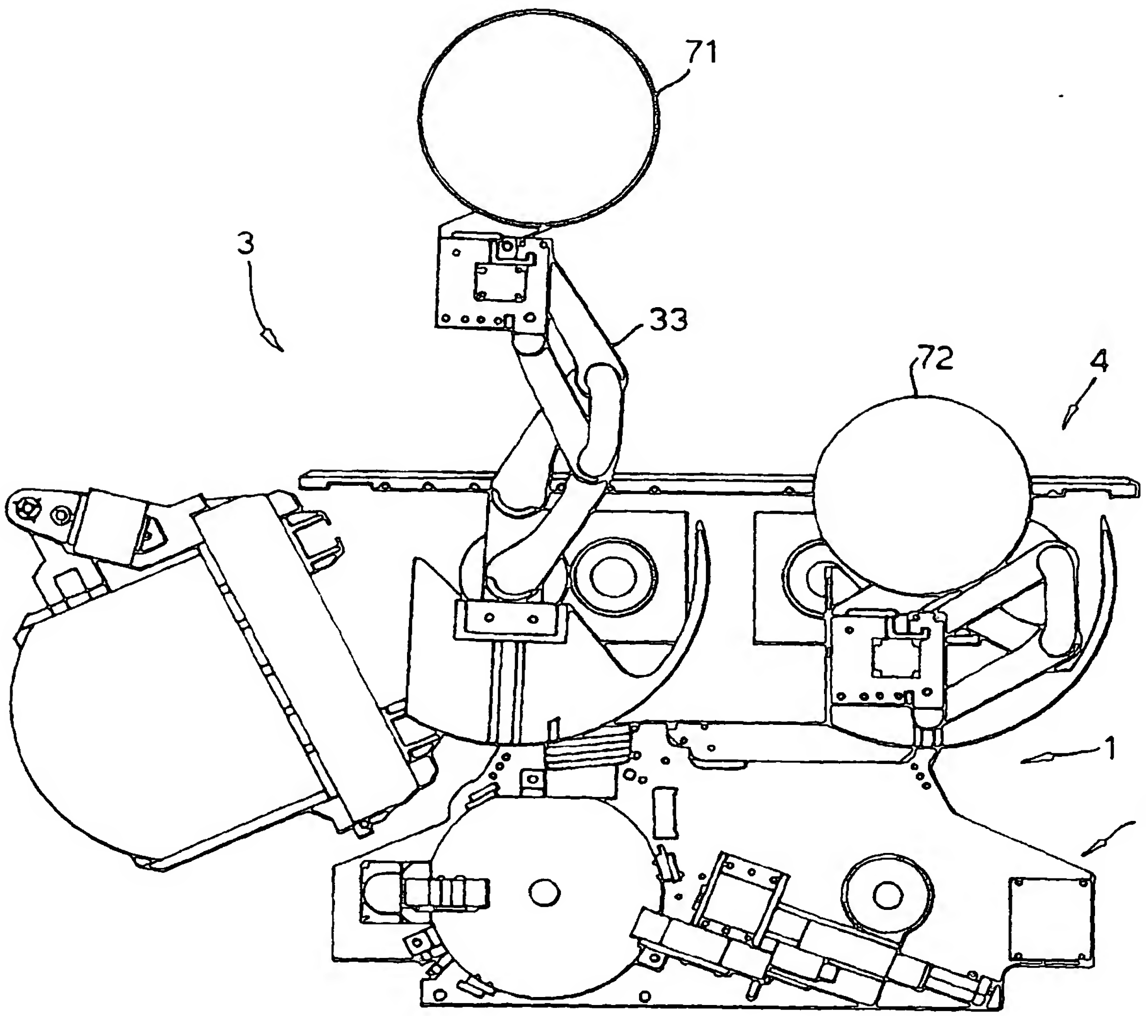


Fig.5A.

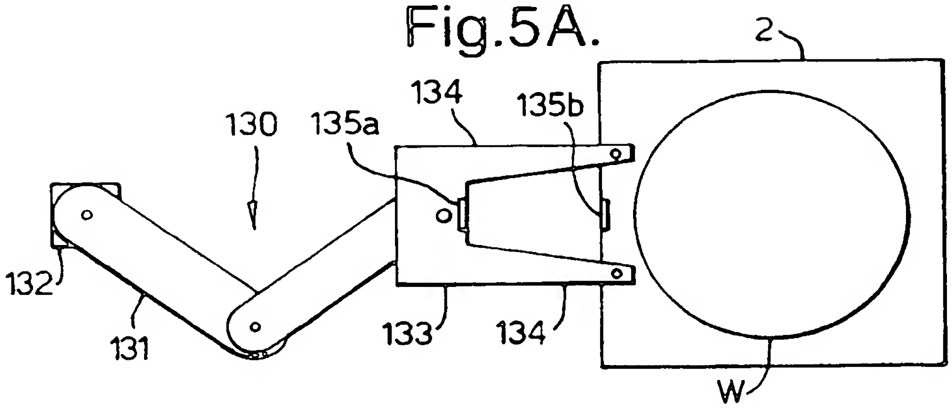


Fig.5B.

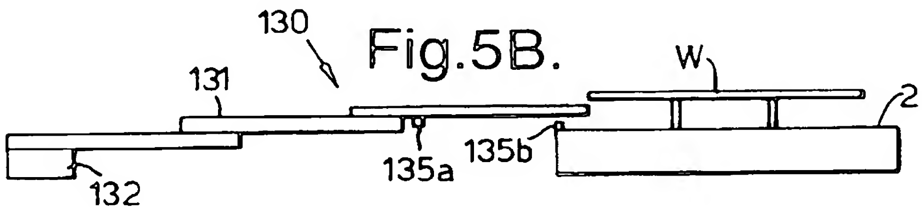


Fig.5C.

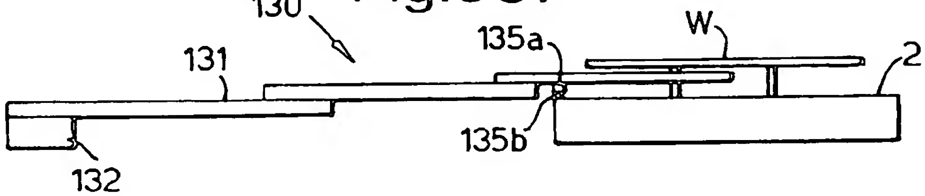


Fig.6A.

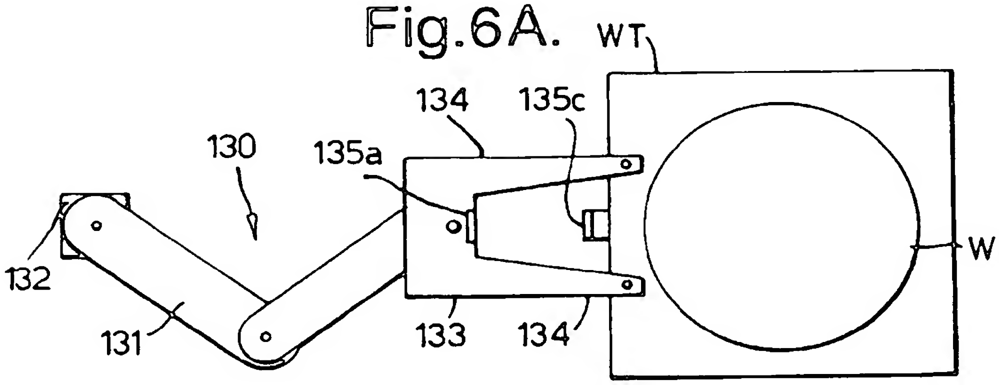


Fig.6B.

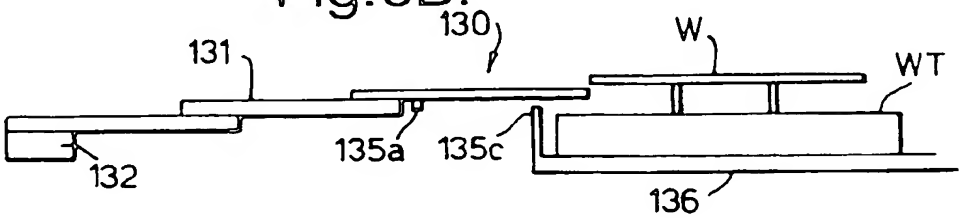


Fig.7.

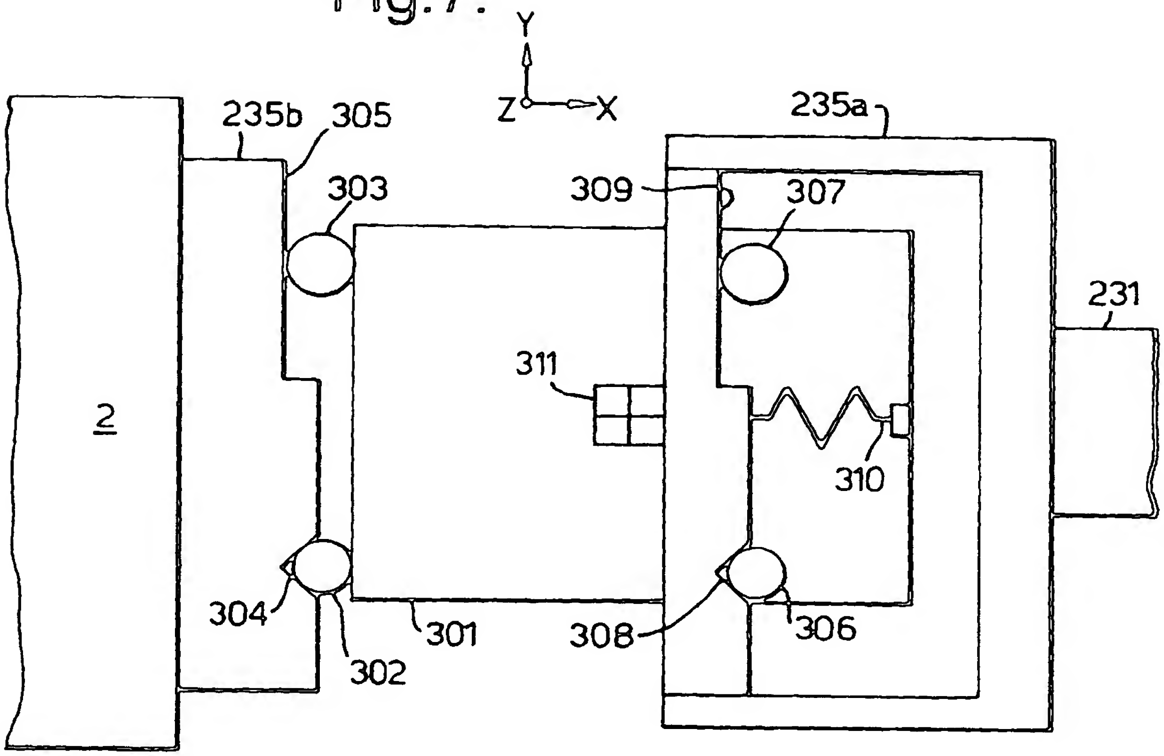

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Fig.8.

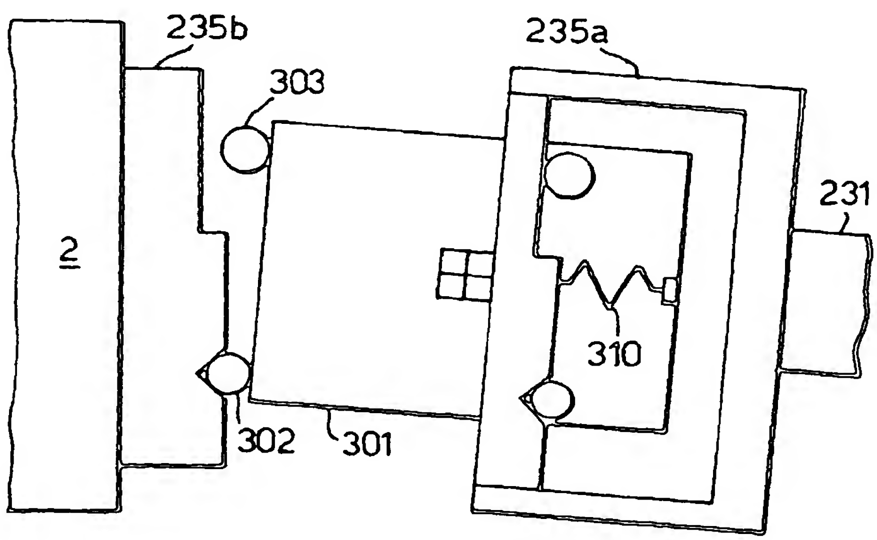
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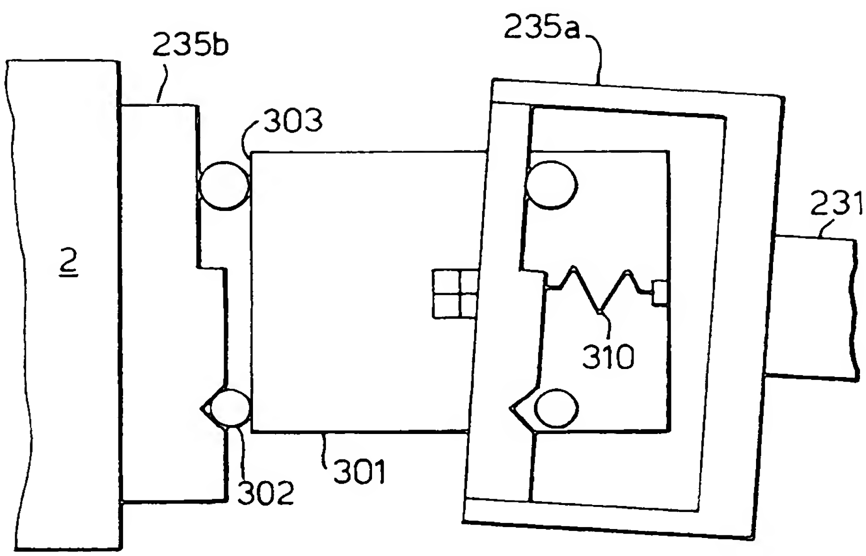
Fig.9.



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(71) Applicant: ASM LITHOGRAPHY B.V.
5503 LA Veldhoven (NL)

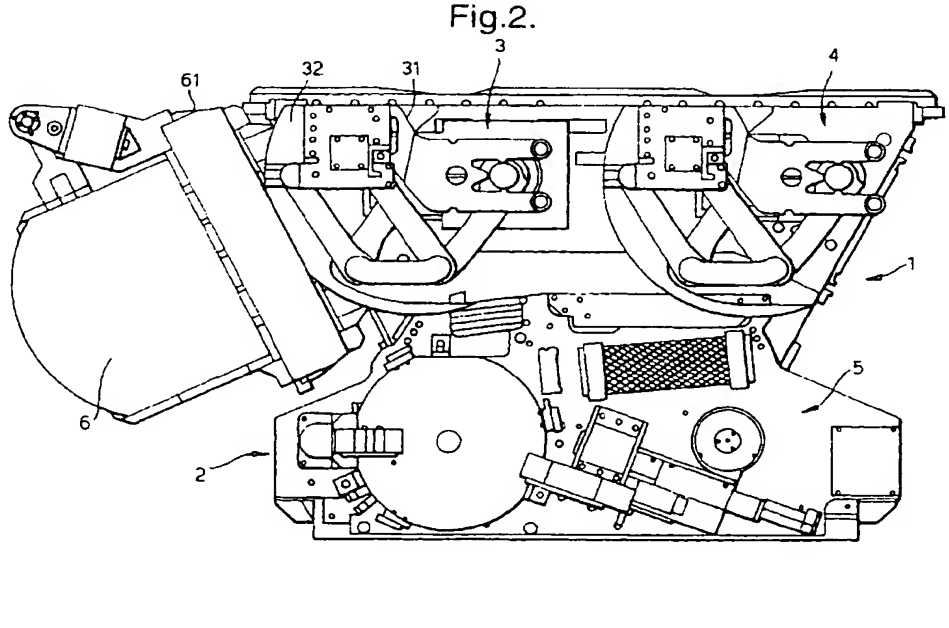
(72) Inventors:
- Segers, Hubert Marie
5212 's Hertogenbosch (NL)
- Boon, Rudolf Maria
5653 RM Eindhoven (NL)
- Bijnagte, Anton Adriaan
4196 AB Tricht (NL)
- Jacobs, Fransiscus Mathijs
5721 DE Asten (NL)

(74) Representative: Leeming, John Gerard
J.A. Kemp & Co.,
14 South Square,
Gray's Inn
London WC1R 5JJ (GB)

(54) **Substrate handler for use in lithographic projection apparatus**

(57) A pre-aligner receives wafers from a wafer carrier of process track and performs preparatory steps such as centering of the wafer. The prepared wafer is transferred to the wafer table using a robot arm that is isolated from the pre-aligner and the wafer table. The robot arm couples to the pre-aligner to pick-up the wafer, decouples, couples to the wafer table and deposits the wafer. Positional accuracy of the wafer is thereby maintained during the transfer.

Fig.2.



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EUROPEAN SEARCH REPORT

Application Number
EP 00 30 2997

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 3 865 254 A (K.H.JOHANNSMEIER) 11 February 1975 (1975-02-11) * column 4 - column 8; figures 1-8 * ---	1	G03F7/20
A	WO 98 40791 A (KONINKLIJKE PHILIPS ELECTRONICS) 17 September 1998 (1998-09-17) * page 5 - page 13; figures 1-4 * ---	1	
A	US 4 655 584 A (H.TANAKA) 7 April 1987 (1987-04-07) * column 3 - column 9; figures 1-9 * -----	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
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Ultrasonic Sensor-based Motion Control for Robotic Manipulators

Chidambar Ganesh, Greg Dietz, and Jon Jambor

Automated Systems Laboratory, Department of Engineering, Colorado School of Mines

In this paper, a two-level hierarchial control structure is utilized to achieve motion-control of a robotic manipulator. A high-directionality ultrasonic distance ranging device is utilized to measure features of interest in the workspace of the robot arm, (in contrast with most prior work that has used wide-angle field-of-view systems such as the Polaroid sensor). Off-line trajectory planning is combined with on-line motion guidance by the supervisory controller to formulate and execute the desired path movement.

In a demonstration application, the vertical distance from a workpiece surface was measured and utilized to perform on-line trajectory adjustment for the robot cutting-tool motion. This enables compensation for factors such as robot performance limitations, inaccurate fixturing and inexact object location. The hardware implementation and control strategy used to provide verification of the concept are presented, along with the experimental results achieved.

1. INTRODUCTION

The primary motivation for this work is to provide enhancements to currently available robot systems to upgrade task performance to within acceptable tolerance limits. The current thrust in intelligent robotics, in which real-time adaptive behaviour is based on high-speed sensor feedback and control, reflects this need. Typically, it is desired to adjust the trajectory of the robot during task performance relative to an object whose exact position is not rigorously predetermined or specified [9].

In this work, we utilize a simple device, an ultrasonic distance-ranging sensor, to measure features of interest of the workspace of the robot. As has been noted repeatedly in the literature ([3],[4]) the primary limitation with a wide angle beam-width is that the exact location and range of the reflecting object is only loosely determined. The novelty of the approach adopted here is the usage of narrow angular field-of-view (2°) sensors, as opposed to previous work where the cone of emission has been 20° or more (see [2] and the references therein).

In our demonstration application, the vertical distance from an object to be operated on with a dremel tool is measured. The robot trajectory is corrected to within required bound of motion relative to the workpiece, despite inaccurate fixturing, variations in robot performance and inexact position specification of the object Motion adjustment to the trajectory is performed on-line by a supervisory controller based on feedback from the sensor. Experimental results on a CIMCORP DK-P600 industrial welding robot are presented that illustrate considerable performance enhancement for ultrasonic sensor based motion control.

2. MOTION CONTROL STRATEGY

2.1 Implementation for Proof-of-Concept

Ultrasonic distance-ranging transducers were used to estimate the "feature" in an example task: in this instance, the vertical distance to a surface which varied over the x-y plane of the robot trajectory, and was determined by the length of the tool to be used. The demonstration task to be performed was a cutting operation, hence it was essential to have the tool-tip track the surface of the workpiece within rigid tolerance limits in spite of inaccuracies such as inexact object location and orientation, loose fixturing on a sloping floor and the inherent limitations of the robots' performance capabilities.

The initial trajectory for the tool-tip is computed off-line, prior to the beginning of the motion and may be generated in a number of ways. Typically, this "first-pass" trajectory is pre-programmed with a teach pendant to describe an operation on a workpiece. Alternatively, it could be a trajectory generated based on information from a CAD data base, or may be computed by an intelligent task planner that decides on the motion strategy for the robot.

As the robot moves through its first-pass, range measurements are made of the distance to the workpiece surface; and the vertical correction to achieve a desired distance is computed

$$e = f_d - f_a$$

The actual joint angles are measured via the robots internal state measurement system of encoders, and passed through a forward kinematic routine to obtain the cartesian position of the robot

$$\underline{X_a} = F(\underline{\Theta_a})$$

Then $\underline{X_d} = \underline{X_a} + \underline{e}$, where $e^1 = [ooe]$

and adjusted trajectory point in terms of joint angle is computed by an inverse kinematics routine

$$\underline{\Theta_d} = F^{-1}(\underline{X_d})$$

This sequence of corrected trajectory points constitutes the "second-pass" or actual motion of the robot arm. The motion adjustment is computed on-line while the robot is moving through and making ultrasonic distance measurements. This sensor-based feedback loop is external to the P-D position control servo scheme of the robot; shich is a digital control system provided by the manufacturer.

2.2 Sensor Considerations

A fundamental limitation encountered by researchers using ultrasonic distance-ranging devices is determining the direction and exact range to the object detected [2]. This is especially true for commonly used sensors such as the Polaroid range finder, which has a cone of emission of about 30° [8]. Various strategies have been utilized to circumvent direct interpretation of a sensor reading-multiple sensors with partially overlapping beam patterns are used in a technique

called beam-splitting. In [3], a method is described for obtaining the true direction to a planar surface using three sensors or three positions of a sensor. This work also describes extension of local feature extraction techniques to perform surface tracking for the extraction of global surface features. In [4], a probabilistic approach to the recovery of spatial information from multiple sources of sonar range data is used to avoid direct interpretation of sensor readings.

This problem of wide angle beam-width was overcome by utilizing transducers with a narrow angular field-of-view of approximately 2^{o}--the UAI DMS--1000 [10], which is specifically designed for high directionality. These narrow beam widths are typical of ultrasound systems used in medicine for imaging applications [5]. Narrow beam-widths, formed by phased array techniques, are also used in advanced side-looking sonar systems for submersibles. Such a sensor would not be suitable in a mobile robot application since object detection requires that the surface be normal to the incident rays, and hence to obtain a wide field-of-view multiple transducers would be required. However, for a fixed-base manipulator arm in a structured workspace with identifiable features such a system is found to be appropriate.

2.3 Experimental Details

The supervisory controller that performs the above sequence of off-line trajectory planning, sensor control, adjusted path computation, and on-line motion guidance is implemented on an IBM PS/2 Model 80. The robot system consisting of the manipulator arm plus its associated controller is treated as a lower-level device that is at the same level as the sensor system. The combination of a serial processing unit and a sequential communications device (between robot controller, sensors and host computer) limits the operation to being a "two-pass" system. Current work is concerned with developing a parallel approach to the computing requirements that would enable simultaneous feature estimation and motion adjustment.

The demonstration task for this application is a cutting operation, hence it was crucial to have the end-effector maintain a constant vertical distance over the surface of the workpiece equal to the length of the dremel tool that was used. Prior to the implementation of the complete system, extensive testing was done to verify the ability of the control scheme to provide satisfactory performance in terms of the above criterion. A novel feature of the system is automatic generation of software in teh higher level robot programming language, CIMPLER. The final, corrected trajectory is defined through a macro-routine with DATA, PATH, and MOVE statements; which is automatically downloaded from the supervisory controller to the robot controller and executed to perform the motion.

3.0 RESULTS AND CONCLUSION

Fig. 1 displays the performance enhancement obtained with ultrasonic distance-ranging when the robot arm was used to track the surface of a table that is non-uniform and placed on a sloping floor. The variation in the initial trajectory is as much as 10mm, whereas with feedback the total error is less than 1mm (which is within the measurement accuracy of the sensors). This was found to be the case over a wide range of x-y plane trajectories, including randomly generated ones spanning a 400mm x 600mm surface.

Such a motion-control strategy would prove of utility in a manufacturing environment, where the scheme would provide compensation for inexact location of parts and/or workpieces. It would loosen tolerance requirements on mechanical fixturing, which play a major role in installation costs. This is a cost-effective alternative to current systems such as machine vision or a laser range-finder in applications where accuracy requirments are not very stringent, and a non-contact alternative to mechanical gauging systems.

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Fig : Performance Enhancement With Ultrasonic Distance Ranging